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Art. V.—*Notes on the Coastal Physiography of Port Campbell, Victoria.*

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(With Plates VI., VII.)

[Read 14th July, 1927.]

Introduction.

The Port Campbell area lies between Cape Otway and Warrnambool, and its coast is justly famed for its magnificent scenery. Inland, the country forms a gently undulating plain of sedimentation, rising at the coast in places to a height above sea-level of over 200 feet, and being destitute of timber near the ocean. The rocks composing this plain are Tertiary sediments, which have been so slightly disturbed that they lie very close to the horizontal. The country has been comparatively little eroded. There are no large streams, the most prominent being the Port Campbell Creek (at the mouth of which the small township of Port Campbell is situated) and the Sherbrooke River, a few miles to the east of Port Campbell. Both these streams, and some smaller ones, enter the ocean at sea-level; but numerous small watercourses and other channels that are mere gulches in the cliffs, occupy hanging valleys. By reason of the non-resistant character of most of the rocks, the valleys are fairly wide, open ones, with rather gently-sloping sides. In some valleys, as in parts of that of the Port Campbell Creek, the valley-sides tend to be steep, owing to the intercalation, high up, of bands of indurated limestone. The Port Campbell Creek, in its lower portion, is sluggish, and its valley flat-floored and marshy, features no doubt at least partly due to the formation of the small bar to be referred to immediately.

The coast-line consists of rugged cliffs, and its general outline is so simple that there are practically no harbours, with the exception of the tiny one of Port Campbell, which lies at the mouth of the creek of the same name, and is about 150 yards wide by about 250 yards long. The head of that "harbour" has been determined by the formation of a crescentic sand bar, capped by a low sand dune across the valley, which it almost closes, the exit of the stream being by a narrow channel on the western side. The bar provides an excellent bathing beach. The western and eastern sides of the "harbour" are formed of steep cliffs in process of marine abrasion.

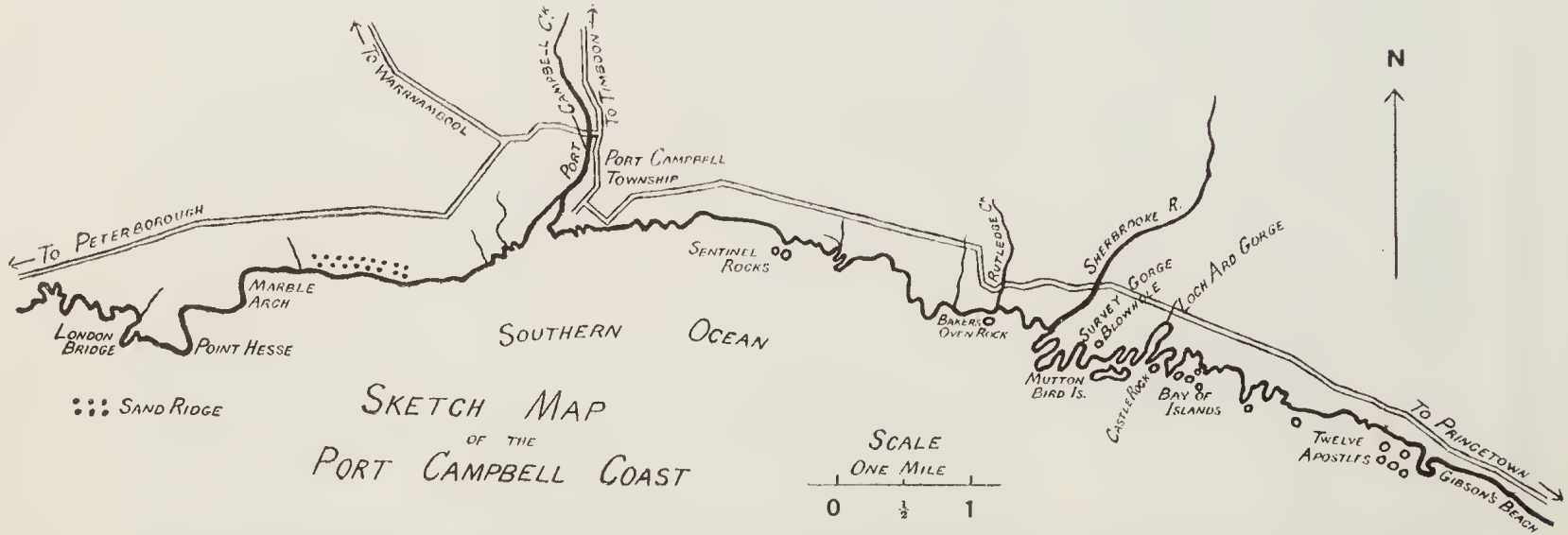

Fig. 1.—Sketch map of the Port Campbell coast, comprising the area referred to in the paper. The map was copied from one available at Port Campbell and appears to be approximately correct. Its authorship is unknown to the writer.

The site of the township on the left bank of the stream has been determined by the fact that there the left side of the valley possesses a long gentle slope, whilst the right side rises precipitously from the valley floor.

The impure limestone, referred to below, is used for road-making in the district.

Previous Literature.

The only previous physiographic references that the writer is aware of are those of J. W. Gregory (1, p. 40) and A. V. G. James (2, pp. 144 and 194) by each of whom Port Campbell (i.e. the "harbour") is referred to as a drowned river valley, and by Gregory also as an example of a ria (1, p. 56).

Physiographic Features of the Coast-Line.

In its general features, the coast-line may be described as consisting of a series of high cliffs, practically vertical, and in places overhanging, which frequently follow a sinuous line (which may be described as "crenulate," although here not necessarily indicating a youthful submerged shoreline (3, p. 278)), owing to the occurrence of numerous small bays and narrow gorges, the latter of which in some instances are continued some distance underground as sea caves, as shown by the "Thunder Cave" at the Survey Gorge; by "the Blowhole" at a point perhaps 200 yards inland, where the roof of the long horizontal cave has fallen in; and by Tom Pierce's and Miss Carmichael's caves in the Loch Ard Gorge. Tom Pierce's cave is about 40 or 50 feet long, 15 to 20 feet wide, and 10 to 15 feet high at the entrance, but becoming so low that one cannot stand erect in it; whilst Miss Carmichael's cave is about 50 feet or more long, 15 to 20 feet wide, and in places 20 feet high. Many of the bays, however, are slight open indentations. The gorges themselves are but a few yards wide and, as a rule, would be about 100 yards in length.

Arches also are formed by marine erosion of opposite faces of small peninsulas or islands. Examples of such arches occur at the peninsula known as "London Bridge," about five miles west of Port Campbell; at a small projecting tongue of land to the north-east of Point Hesse, where it is known as the "Marble Arch"; and in an island in the small "bay" immediately to the east of the Loch Ard Gorge.

Islets, usually with vertical cliffs, are fairly common—a rather unusual feature of the Victorian coast-line.

The rocks forming the cliffs are chiefly Tertiary shales, fine-grained sandstones, and impure limestones. The lower beds largely consist of easily eroded shales, with an occasional harder band, whilst those towards the top of the cliff have been made more resistant to erosion by the deposition of ferruginous or calcareous material in the form of thin bands along the bedding

planes, and also as nodules and irregular masses.[1] These features, therefore, by aiding marine abrasion, and by retarding atmospheric erosion, facilitate the formation and maintenance of practically vertical cliffs, without (under the present stage of development) materially checking the rapid recession of the cliffs. The attack of the waves on a soft band of rock is greatly aided by its horizontal character. This is shown by the undermining along such a stratum, both when the direction of attack is approximately at right angles, and when, in consequence of a projecting strip of land, the direction of attack is parallel to the trend of the coast. In the latter case, it is very instructive to watch the end of a wave working along the stratum, and to note the even groove made by such action.

The hanging valleys indicate that the cliffs are receding faster than these valleys can deepen themselves, and so the latter do not reach the sea-coast at sea-level.

Cliff erosion is also assisted by the presence of pronounced, usually vertical joints, fairly widely spaced, often forming two sets, more or less at right angles to each other, sometimes very curving and sometimes dipping into the cliff. The undermining of the cliffs, their steep character, and the percolation and evaporation of water along these joints, bring about the fall of huge masses usually rectangular in cross-section; and the new face of the cliff consequently presents a somewhat buttressed appearance.

A striking feature of the coast-line is the number of taluses formed as a result of the processes just described, many of the component blocks of which are of great size. These masses, being particularly exposed to the action of the sea and of the weather, must be removed relatively rapidly.

Broad well-developed beaches and water-worn pebbles and boulders are scarce. Beaches at the foot of the cliffs in the bays do occur; but usually they are narrow and the sand scanty. Many are accessible at low tide only, and in some parts they are probably always inaccessible. One of the best beaches is that in the bay immediately to the west of London Bridge. The waterworn boulders, when naturally occurring, may have been largely removed for the purpose of roadmaking, as several heaps, gathered together for this purpose, of the fairly hard, impure limestone were noticed at the time of the writer's visit in January, 1925.[2] If, however, boulders and shingle are generally absent from the beaches, it is a matter of some surprise, considering the quantity of resistant rocks in the cliff beds.

1.—One result of the occurrence and irregular distribution of these harder bands is the formation by differential weathering of pillars of comparatively soft rock with projecting hard caps. Where a considerable area of the rocks has been exposed, as at the tops of the cliffs just to the west of Point Hesse and near the "Blowhole," close to the Loch Ard Gorge, the surface becomes honeycombed and extremely uneven and ragged, with varied and often grotesque forms.

2.—These collected waterworn rocks may possibly be due to stream action; but if so, whence they came is unknown to the writer.

The comparatively short and few streams entering the sea in this area cause little fluviatile detritus to be carried into the sea; hence the waves are freed from the task of removing the material that would otherwise be deposited near the shore, and are thus enabled to make a more continuous attack on the coast.

Wave-cut rock platforms lie at the base of the cliffs and around the stacks, which are comparatively close to the shore; but whether or not these platforms stretch seaward to any extent was not observable, although waves frequently break far out, thus suggesting the continuance of the platforms to those areas.

One obstacle to marine abrasion is the occurrence of the great seaweed commonly known as "kelp," which in many places is so firmly attached to the rocks at sea-level, and is so abundant, that rock removal must be considerably checked.

As a result of the powerful marine abrasion, a coast-line has been produced which in certain parts is very broken on a small scale. These features are observable in the vicinity of London Bridge, and especially at and adjacent to the Loch Ard Gorge. Diminutive bays and gorges succeed one another, and a moderate number of islets fringe the shore in places. A physiographer without personal knowledge of the area, looking at a map of the coast-line drawn on a fairly large scale, would probably infer that the physiographic features referred to are due to a recent submergence of the land. This question is subsequently discussed, but here it may be pointed out that although slight submergence may have taken place, and although the "harbour" of Port Campbell[3] may possibly be due to submergence, yet practically no traces of submergence remain; and the small bays and gorges are clearly due to erosion, as they certainly are not the drowned ends of normal valleys. Moreover, their actual formation can be seen now going on.

Reflection might suggest that the gorges occur only at the mouths of valleys, and that consequently, even though they are not drowned valleys, their erosion by the waves has been hastened, owing to the formation of the valley above, and the action of waterfalls (where the valleys are "hanging" ones) in bringing about a recession of the cliffs upstream. But although gorges do occur as indicated, yet there are others quite as long, which have been formed without these aids, and therefore the ocean is responsible for the whole gorge in certain cases. Doubtless where strong seas—as at Port Campbell—are available, they gather force by concentration in a narrow area, despite the increased friction they suffer. Hence if breaches are made in a cliff face, the concentrated power of the water will tend to erode gorges—at least in soft rocks—at the head of which extensive sea-caves may be formed, as for example, in the Lord Ard and Survey Gorges.

3.—The mouth of the Sherbrooke River was not examined by the writer, so that no expression of opinion can be given as to whether or not it represents a drowned river valley.

One would imagine, however, that there must at least be a temporary limit to the extension of the gorges, owing to the continually increasing friction and consequently reduced power of the waves as the gorges lengthen; but the activity of the sea may be revived as the outer cliffs are cut back.

The formation of such gorges might be expected if there were much variation in the power of resistance to marine abrasion of the rocks of the coast, but such variation at Port Campbell is not apparent on a general inspection; hence some surprise is excited by their occurrence. There must, however, be differences in resisting-power among the rocks, although difficult to detect; and perhaps wave-attack varies in strength from point to point.

The gorges, however, may be primarily or largely determined by structural features, such as strong joints or small faults highly developed in certain areas; since erosion would advance more rapidly along these lines of weakness than in areas where they were absent, other things being equal. This aspect was suggested to the writer by Professor Skeats, but it must be reserved for future investigation.

The numerous islets are due to marine abrasion, and not to submergence of the land; their shape and distribution, and their standing, as far as can be seen, upon a wave-cut platform negativing the latter idea. In a mainland so little dissected, such islets could not result from subsidence. They are, therefore, undoubtedly stacks. None of these stacks is joined to the mainland or to another stack by a sand bar, this fact being no doubt due to the rapid removal by the waves of most of the detritus from the cliffs.

The scarcity of beaches is apparently due to the tremendous scour of the waves, and to the fineness of the constituents of the rocks attacked. Such rocks yield little sand, and the fine materials are carried well out to sea. Moreover, the absence of much river-borne detritus must tend to restrict the formation of beaches. This limitation of beaches hastens in turn the wearing away of the cliffs owing to their lack of protection by the beaches. Two localities are of interest as minor examples of the prevention of wave attack. In the western arm of the Loch Ard Gorge a high bank of blown sand is preventing—but probably only temporarily—further marine abrasion of the cliffs around this arm. In the small bay just west of "London Bridge," where there is a well-developed beach, a small dune at one point acts in the same way. In each case, rough thick stalactites have formed on the inwardly-inclined cliff, so that the cessation of wave attack is not quite recent. Incidentally, it may be noticed that if man removes sand and gravel from the shore, such action will hasten the wearing away of the cliffs by the sea.

A little to the west of the large sand ridge described below, there is on the beach a large bed of rounded pebbles and boulders, covered with vegetation, in front of a talus, which thus at present protects the cliffs from marine abrasion.

A striking feature observable in some localities is the small serrations in the Tertiary rocks at the top of the cliffs. The serrations have been filled with red soil containing ironstone fragments, which deposit in many places forms a thin surface cover on the marine Tertiary sediments. The origin and age of this deposit are not obvious, although it appears to be of quite recent age, and to have been laid down subaerially.

Reclamation of Land from the Sea.

The physiographic features noted above are so characteristic of the coast that much surprise is felt when a long sand ridge is found abutting the coast. It commences a few hundred yards west of

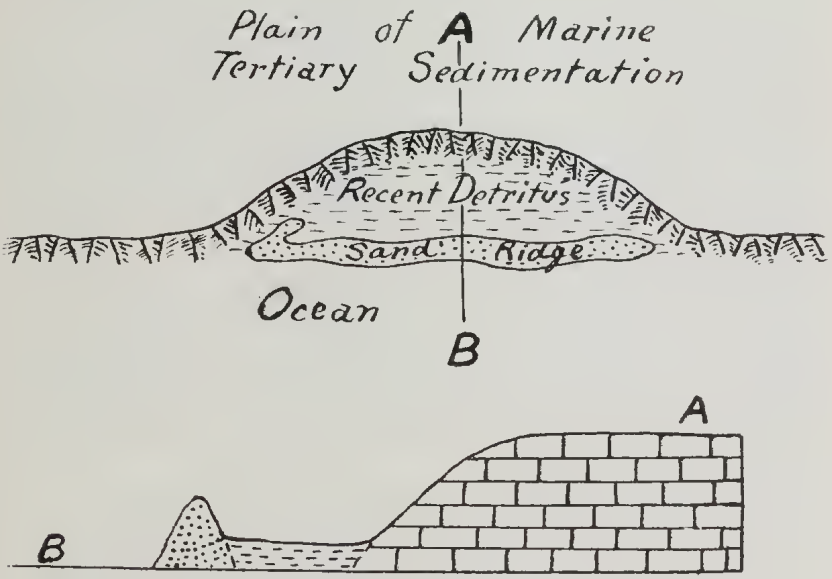

Fig. 2.—Diagrammatic plan and section of the sand ridge area west of Port Campbell.

Port Campbell "harbour" and extends in a gently curving line westerly for perhaps three-quarters of a mile. It follows the coast-line so closely that at high tide the water reaches to its base. The ridge varies in height, the highest point being about 80 feet above sea-level. Its crest usually is not more than a few feet wide, and its width at the base varies from a few yards to about 25 yards. It is clothed, but not densely, with vegetation, mostly small shrubs, but there is ample opportunity for movement of the sand by the wind. The sand is fine-grained, and, so far as cursorily examined, consists chiefly of quartz. At its western end, the sand ridge throws off inland a short minor ridge, which divides into two, but reunites. Near the eastern end, the sand

rests for a short distance on a rock platform six to eight feet above the beach.

At each end of the main ridge the coast-line consists of precipitous cliffs up to 200 feet or more high, of the kind already described as characteristic of the coast as a whole. These sea cliffs are being abraded strongly by the ocean. Although they give place to the sand ridge along the coast, yet they are connected behind the ridge by a line of cliffs (which for convenience may be referred to as the "inland cliffs") which forms an arc of which the sand ridge is the chord.

The inland cliffs present a striking contrast with the present sea cliffs in that they are clothed with vegetation; show the double curve of atmospheric denudation in profile; are not vertical, although steep; are not undermined; and have alluvial fans at the mouths of the small creeks or gullies that dissect them. These features are absent in the sea cliffs, as will be seen from the description given above of the coast generally. What are apparently old taluses occur at the foot of the inland cliffs, but these may have been formed either under marine or atmospheric conditions. Another contrast is that the gullies and short creeks which cut the inland cliffs are not hanging like those of the sea cliffs. This points to rapid recession of the latter, but to very slow backward cutting of the former.

Between the inland cliffs and the sand ridge is a narrow belt of low-lying land possessing a somewhat uneven floor, owing to the formation of the alluvial fans mentioned above, to the probable drifting of sand from the sand ridge, and to some slight stream action. The greatest width of this belt is about 70 or 80 yards, and in its higher portions its surface is probably 25 feet or more above sea-level.

The obvious interpretation of the phenomena described is that the line of inland cliffs was originally bounded by the sea; that the sand ridge was thrown up by the waves and wind, forming a typical bay dune-covered bar, which either altogether or almost entirely cut off the sea behind it from the ocean; that silting (or perhaps silting combined with uplift) has taken place until the water has given place to land; that subsequently thereto, by the accumulation of wind-driven sand from the ridge and of detritus from the gullies and face of the inland cliffs, the land surface of this reclaimed area has been raised to its present height; and that by atmospheric erosion the face of the inland cliffs has been changed from their typical sea-front form in this locality to the equally typical double curve of atmospheric denudation.

This interpretation appears to meet the facts of the case best, although others are possible. It is, however, uncertain, on the facts known to the writer, whether uplift has played any part in bringing about the present conditions.

It may be contended that the bay which has been cut off penetrated far enough into the coast-line for the water to become rela-

tively quiet, and silting to occur—resulting in the formation of land—without necessarily the formation of a bar, and that the land gradually encroached on the sea, until the present coast-line was approximately fixed, after which the sand ridge was formed by wind action. Against this idea is the fact that the coast-line in the neighbourhood is much indented on a small scale by the abrasive action of the waves, and in several instances the indentations are quite as pronounced and some are more sheltered than the bay referred to, and yet in almost all these localities wave abrasion is still actively proceeding.

Another point requiring consideration is that at the eastern end of the sand ridge, the rock platform already referred to, stands six to eight feet above the present beach. This fact suggests that if that platform were originally continuous across the bay to the inland cliffs, and had been formed as a platform of marine abrasion, it could hardly have been formed at its present height, and hence a recent uplift of the land relative to the sea may have occurred; and in that event the change from sea to land would be effected merely by the uplift and not by silting. No direct evidence of such an uplift in the immediate neighbourhood of the bay was noticed (except possibly just to the west of the sand ridge, where some waterworn pebbles and boulders fill some hollows in the cliffs at a height of about eight feet above the beach, but these might also be regarded as the remains of a storm beach) although such evidence, if it originally existed, would no doubt usually be rapidly destroyed, except that, in other indentations, remnants of similar platforms should be observable. Whether or no such a platform exists in the old bay behind the sand ridge cannot at present be stated, as its surface, if it exist, is covered with recent debris—the wash from the inland cliffs and the sand from the sand ridge. On the whole, however, doubt is thrown on the existence of a wide platform by reason of the fact that no evidence of its occurrence is found along the greater part of the sea margin of the ridge, and on account of the absence of such platforms in neighbouring indentations. Moreover, the rock platform under the sand ridge can be explained on the assumption that it is an old low stack.

A short bore or some shallow excavations in the low-lying ground might yield some interesting results.

The sand ridge cannot be regarded as quite fixed, as the vegetation is sufficiently scattered to allow the sand to be carried by the wind over the crest landward. In this way, if there be no erosion of the sand ridge, the ridge must be increasing in width. There is evidence however, in some places, of the erosion by the sea (which would be expected, seeing that the cliffs at each end of the ridge are being cut back) with the result that the vegetation has in places been destroyed, and the loose sand is partly being removed by the sea and partly being carried by the wind over the ridge landward. As the strength of the marine abrasion on this coast is not likely to abate for some time to come, the sand ridge

must either be removed or migrate. The fact that the reclamation of the old bay and the modification noticed above of the forms of the inland cliffs have apparently taken place since the formation of the sand ridge, indicates some degree of antiquity for the sand ridge; and the most feasible explanation of why the ridge has been able to maintain its identity for so long a period, despite marine abrasion, is that the latter process is counter-balanced by the deposition of wind-blown sand on the landward face of the ridge. Consequently the ridge may be migrating towards the inland cliffs. If this be so, an interesting point is, assuming these conditions to continue, whether or no the ridge will reach the inland cliffs, and be banked against, and temporarily protect from erosion the latter. This in turn will depend on the rate of migration of the sand ridge and the rate of erosion of the inland cliffs, points about which at present we know nothing.

The Stage of Development of the Coast.

D. W. Johnson (3, p. 249) distinguishes between the shore profile and shoreline development. They may be in the same or in different stages, so that if one be young or mature, the other is not necessarily in that particular stage.

In the Port Campbell district, the vertical high cliffs, their rapid erosion, the stacks and the scanty beaches indicate that the shore profile is in the youthful stage; whilst on the other hand the simply curved coast-line (apart from the minute irregularities caused by the small bays and gorges) the absence of spits, bay-bars (with the exception of that referred to in detail above), tombolos and offshore bars, indicate that the stage of shoreline development is mature.

Whether the coast-line was originally one of submergence or of emergence, or is due primarily to faulting, is difficult at present to say. The existing forms of the shore profile and of the shoreline could result from any of the types mentioned. If it were one of submergence, then the drowned valleys (except the "harbour" of Port Campbell and possibly the mouth of Sherbrooke River, assuming them for the moment to be such) together with any associated phenomena, such as spits and bay-bars, have been removed by marine abrasion. Similarly, if it were one of emergence, the offshore bar, the lagoon and possible marsh (if these features or any of them occurred) and the low-lying land of the uplifted coastal plain have been removed. In the same way, a fault-coast would have been retrograded.

The absence of any direct evidence of recent uplift has been referred to in the immediately preceding section of this paper. It may here, however, be pointed out that if a small uplift could be proved to have taken place, such would almost certainly establish the fact of a prior submergence, since the bed of the Port Campbell Creek is now so close to sea-level that, if it has

recently been raised several feet, it must have been an estuary prior thereto for some distance from its mouth.

As regards direct evidence of submergence, there is none with the possible exception of Port Campbell "harbour" and the mouth (not seen by the writer) of the Sherbrooke River. But so far as concerns the "harbour," in view of the evidence adduced above as to the power of the ocean to excavate small bays and gorges; of the fact that the stream has provided a well-defined opening in the cliffs which the sea could easily further widen; of the fact that wave-cut platforms and cliffs do exist inside the "harbour"; and of the short distance the sea penetrates, it cannot be assumed from the mere form of the "harbour" that it represents a drowned portion of a valley. Of course the shortness of the "harbour" could be accounted for either by the building, in the old estuary, of the dune-covered bar already described, owing to which—above the bar—siltation has taken place and marshes have resulted[4], or by the retrogradation of the shoreline, or by both these operations, the second of which we may be sure has been in force.

The writer has been permitted, by the courtesy of Captain J. K. Davis, Director of Navigation, to inspect the charts of the ocean in the vicinity of Port Campbell, but no definite conclusions regarding the questions discussed in this paper can be drawn from them, although such might be possible, were greater detail shown.

Judgment on the original character of the shoreline must therefore be suspended pending an examination of a wider area.

It may be noted that G. S. Griffiths (5, pp. 76-79) states there is evidence of late submergence and of subsequent emergence at the Portland Promontory. Similar observations have been made in so many places around Australia that one naturally leans towards those ideas at any similar spot under examination. Each locality must, however, be independently judged.

Summary.

The Port Campbell area lies between Cape Otway and Warrnambool. Inland, the country forms a plain of Tertiary marine sedimentation, not much dissected. The coast consists of rugged high vertical cliffs of the same class of rocks.

The coast in places follows a sinuous line owing to the occurrence of small bays and narrow gorges. Arches and long sea-caves are prominent features, and numerous islets occur. These features are due to marine erosion, and not (as regards the bays, gorges and islets) to submergence of pre-existing valleys.

4.—T. S. Hall (4, p. 31) refers to the blocking of the mouths of various streams east of Warrnambool, of which Curdie's and the Gellibrand Rivers are examples, by sand dunes, without apparently believing that their estuaries are drowned valleys. The "harbour" of Port Campbell may be of similar origin.

The upper beds of the coastal cliffs, being somewhat more resistant to erosion than the lower, facilitate the formation and maintenance of practically vertical cliffs. A series of vertical joints also tends to the same result.

Hanging valleys occur in the shorter watercourses, indicating that the sea-cliffs are retreating faster than these valleys can deepen themselves.

Taluses are abundant; but well-developed beaches and water-worn pebbles and boulders are scarce.

Wave-cut platforms occur at the base of the cliffs, but their seaward extent is unknown to the writer.

A prominent sand-ridge runs along the coast to the west of Port Campbell. Behind it lies a belt of low-lying ground which is bounded by a line of old sea-cliffs, which have lost their typical marine form, and have taken on the double curve of atmospheric denudation. The sand ridge is regarded as having been formed as a bar across the mouth of the old bay, and then built up by wind-blown sand. The bay became practically closed to the ocean. Silting occurred, and the low-lying belt at the rear was formed, thus reclaiming a moderate area of land. The question of uplift is considered in this connection, and the conclusion is arrived at that as there is no definite evidence of recent uplift, the probabilities are that the low-lying belt was formed entirely by silting and subsequent atmospheric accumulation. If that be so, the sand ridge must be of some antiquity.

The sand ridge is not fixed. It is being eroded on the seaward side by the ocean, and is widening on the landward side by the deposition of sand blown over it from the seaward face. Consequently the ridge may be migrating landward.

The shore profile is youthful, whilst the stage of shoreline development is mature.

Whether the shoreline was originally one of submergence or emergence, or is due primarily to faulting, has not been determined, although some slight submergence has perhaps taken place.

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Fig. 1.

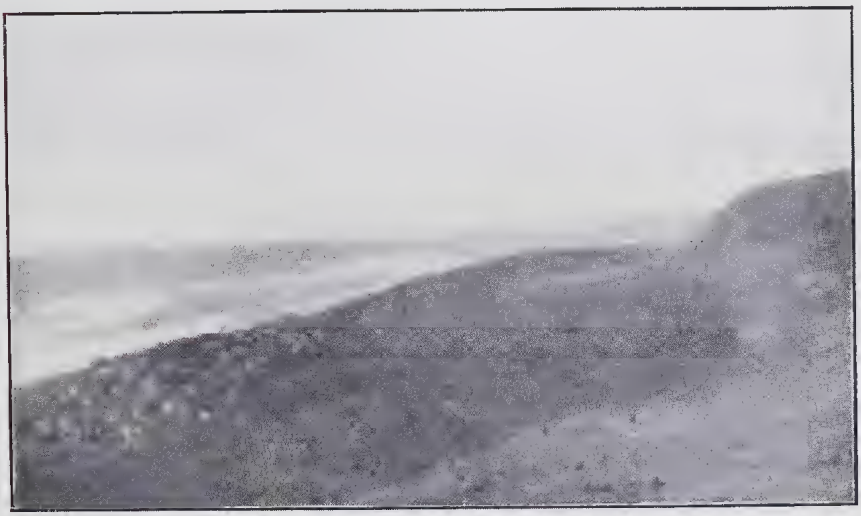

Fig. 2.

A B C

Fig. 3.